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3 Theoretical and Experimental Investigations
of the Microwave Properties of Planetary Atmospheres 4

a) Period: 4 June 15, 1965 - December 31, 1965 7

b) Personnel:

Professor H. Foley	Project Director
Professor R. Novick	Director, Columbia Radiation Laboratory
Dr. P. Thaddeus	Research Scientist
Dr. R. Isler	Research Scientist
William Ho	Graduate Student
Irwin Kaufman	Graduate Student
Supporting Staff of the Columbia Radiation Laboratory	

c) Publications and Reports:

(1) "Microwave Absorption in Models of the Atmosphere of Venus," W. Ho, I. Kaufman, and P. Thaddeus, Bull. Am. Phys. Soc. II, 10, 705 (1965); (2) "The Atmosphere of Venus," P. Thaddeus in Advances in the Astronautical Sciences, 1965, Vol. 19; (3) "Microwave Absorption in Compressed CO₂," W. Ho, I. Kaufman, and P. Thaddeus (in press); (4) "Laboratory Studies

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of Microwave Absorption in Models of the Atmosphere of Venus," W. Ho, I. Kaufman, and P. Thaddeus (in press); (5) "A Microwave Cavity Spectrometer to Measure Absorption in Gases at High Temperature and Pressure," W. Ho and P. Thaddeus (in preparation); (6) Columbia Radiation Laboratory Quarterly Progress Report, June 15, 1965, pp. 58-60; *ibid.*, September 15, 1965, pp. 63-64; *ibid.*, December 15, 1965, pp. 54-55.

Description of Research

The first phase of this work concerning the microwave properties of models of the Venus atmosphere is now completed. Mixtures of carbon dioxide with plausible, cosmically abundant candidates (nitrogen, argon, neon, helium) for the inert major fraction of the atmosphere have been studied over the temperature range 240 to 520°K (-33 to 247°C) and to pressures as high as 130 atm. Theoretical interpretations, based on these laboratory measurements, of the radio and radar studies of Venus, and the results of the Mariner radiometer experiment during the flyby of December 1963 have met with very good success. At the time of the present writing there are few or no radio-frequency observations of Venus which cannot be understood on the basis of the models calculated at the Massachusetts Institute of Technology by Professor Barrett and his students, and at the Goddard Institute for Space Studies by Dr. Thaddeus. Both groups have used the microwave opacities measured as part of the present program.

The most interesting conclusion that has been reached is that if particulate matter such as water droplets plays no large role in the microwave opacities (and there are

spectroscopic indications that this is indeed a good assumption), then the ground pressure on Venus must be large by terrestrial standards. Depending on the exact fraction of CO_2 present, a surface pressure in the range 100-200 atm is calculated.

This result is of great interest to theories of the origin of the solar system, since it suggests that the histories of the Earth and Venus have been quite dissimilar. At the same time, it has a distinct implication for future planetary experiments with spacecraft, for it indicates that, unlike the case with Mars, reentry experiments can be performed employing aerodynamic breaking, and that capsule experiments using straightforward instrumentation (thermometers, pressure gauges, chemical analyzers) will be of great value and interest. This indication of large mass for the Venus atmosphere, together with the recent measurement by radar of the length of the Venus day (249 days retrograde) has recently awakened the interest of the theoretical meteorologist in problems of the general circulation of the planet.

Finally, it should be mentioned that together with the analysis of observations already made, the measured opacities are at this time being used in the design of a proposed microwave occultation experiment for the Mariner flyby planned for 1968. This type of experiment measures the change in amplitude and phase of the spacecraft's telemetry system as it passes behind the planet and requires no additional apparatus. The occultation on the 1965 Mariner Mars was effective in furnishing rather easily interpreted data

relating to the Martian ionosphere and troposphere. One of the model atmospheres studied was pure nitrogen, where we measured the temperature dependence of induced absorption for the first time. This recently proved of use in calculating the expected temperature of the earth's atmosphere in the sub-millimeter and far infrared in preparation for infrared astronomical observations from high altitude balloons.

At the present time most of our attention is being directed toward a study of the effect of trace amounts of water vapor and other polar molecules on the model atmospheres mentioned above. This work is being done with the X-band instrument described in our proposal of a year ago and will constitute a part of the doctoral dissertation of Irwin Kaufman. We have already made a number of runs on varying amounts of H_2O in N_2 at several temperatures and have compared our results with detailed theoretical calculations based on the Van Vleck-Weisskopf theory of pressure broadening. In the region of 100 atm, the observed absorption is about twice that calculated from theory due presumably to the increasing importance of many-body collisions.

We are in the process of applying these measurements to our numerical Venus models and believe it will be possible to give some constraints on the total amount of water vapor present in the planet's atmosphere. It will be very interesting to compare the results with the constraints on the water vapor abundance imposed by the infrared spectral observations. At the same time measurements are being made on heavy water D_2O and HDO traces to help elucidate the nature of pressure broadening at high pressure. We hope during the coming year

to extend this work to other polar molecules, especially ammonia (NH_3), which will be studied in a number of atmospheres and which is, in particular, pertinent to the radio studies of Jupiter.

Our original plans called for eventually adopting the present cavity spectrometer to work at a series of higher frequencies. It has been operating so well at the present frequency of 9260 Mc/sec, however, and has been so fully used that we have been hesitant to make any serious structural modifications. In addition, we realized when we analyzed our results on induced absorption in $\text{CO}_2\text{-N}_2$ atmospheres that higher pressures were at least as important as higher frequencies in understanding the molecular physics of the induced absorption process. During the past few months a new instrument was therefore constructed which operates in the frequency region near 35,000 Mc/sec and which has been tested at over 600 atm. (This represents a factor of four in pressure over any previous work.) A number of technical problems, particularly concerning the coupling window, have been successfully solved.

Since induced absorption (or rather the dielectric loss ϵ'') increases as the square of the pressure and directly as the frequency, we should ultimately attain a sensitivity 10-100 times higher with this instrument than with the present device. At this writing, measurements with the new apparatus are just starting. Our first objective is to measure for pure N_2 the temperature dependence of the first two virial coefficients of the dielectric loss, as we have already done for CO_2 when the effect is 100 times larger. It is also our intention to use this instrument to extend our study of the effect of trace quantities of polar gases on nonpolar atmospheres.